

Evaluation of Gamma Irradiation in Controlling Post-Harvest Rot of Ginger and Improvement of Shelf Life

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Abstract: Gamma irradiation has emerged as a promising method to enhance the shelf life and control of ginger rot after harvesting. By effectively reducing microbial contamination and inhibiting the growth of spoilage organisms, gamma irradiation offers significant potential in improving storage stability and prolonging the freshness of ginger. This study was carried out at the Division of Plant Pathology located at the Bangladesh Institute of Nuclear Agriculture (BINA) in Mymensingh, to explore the effectiveness of Gamma irradiation in controlling post-harvest storage rot caused by *Fusarium oxysporum* in ginger. The study was conducted using a design of complete randomization, and it was replicated three times, and six doses of Gamma irradiation (20, 40, 60, 300, 500, 700 Gy) were applied to ginger rhizomes, which were then stored in three types of containers: natural condition (on brown paper), gunny bag, and poly bag. The experiment also included chemical fungicide, bio-fungicide, and control (without radiation) treatments for comparison. The results showed that the highest suppression of mycelia growth (76.86%) was achieved with a dose of 700Gy. No sprouting was observed at doses of 60, 300, 500, and 700 Gy, even after three months of storage. The lowest incidence of rhizome rot (56.83%, 68.15%, and 87.89% after three months of storage) was recorded at 700Gy on brown paper, gunny bag, and poly bag, respectively. This resulted in a corresponding suppression of rhizome rot of 35.72%, 24.83%, and 12.11% over the control treatment. Overall, Gamma irradiation was found to be advantageous in increasing the shelf life of stored ginger by suppressing sprouting and in lowering the incidence and severity of post-harvest storage rot caused by *Fusarium oxysporum*. Therefore, Gamma irradiation may be considered as a suitable management practice for controlling post-harvest storage rot in ginger, without any adverse environmental effects.

Keywords: Gamma irradiation; Post-harvest; Shelf life; Ginger.

INTRODUCTION

Ginger (*Zingiber officinale*) is a fragrant perennial herb native to Southeast Asia and a member of the Zingiberaceae family. Essential oil (2.5%) is responsible for the aroma, while gingerol, a non-volatile oleoresin, is responsible for the flavor. (Sutarno et al., 1999). A variety of phytochemicals, including zingiberene, -curcumene, gingerols, and shogaols, are abundant in the rhizome or root. These bioactive molecules, which serve as biological and pharmacological antioxidants, are the main ingredients

of ginger nutritional supplements (Lee and Oh, 2013). Currently, ginger is used as a herbal treatment for a number of ailments, such as rheumatism, fever, infectious diseases, indigestion, constipation, indigestion and vomiting, hypertension, dementia, and sprains (Ernst and Pittler, 2000; Shukla and Singh, 2007; Grzanna et al., 2005). Through the modulation of biological activities, ginger has been shown through research over the past ten years to have the potential to be used in the prevention and treatment of a wide range of diseases (Rahmani, 2014). According to Kim et al. (2005) and Hsiang et al. (2013), the primary

pharmacological effects of ginger phytochemicals include immunomodulatory, anti-tumorigenic, anti-inflammatory, anti-apoptotic, anti-hyperglycaemic, anti-lipidemic, and anti-fungal properties. Rhizome is an effective digestive stimulant and carminative. The essential oil is employed in the production of ginger malt as well as for flavoring purposes in food and beverages. Ginger holds a special place among significant spices because of its numerous uses in Bangladesh. Ginger is grown as an annual rain-fed crop in Bangladesh. Important ginger-growing regions include Dinajpur, Rangpur, Tangail, Chittagong, and Rangamati (Pasha et al., 2020). Bangladesh produces about 49,405 M. tons of ginger annually from about 19,055 hectares of land (BAMIS, 2021). The major ginger producing countries are China (11.9 MMT), India (2.12 MMT), Nigeria (0.523 MMT), Indonesia (0.303 MMT), Nepal (0.279 MMT), Thailand (0.0488 MMT), Bangladesh (0.0494 MMT) and Japan (0.0465 MMT) among others (EMR 2021). The above data shows that productivity of ginger in Bangladesh is much lower compared to other countries. The low productivity of ginger in Bangladesh is attributed to many production constrains. Among these, various biotic stresses, diseases, pests cause significant yield losses (Pasha et al., 2020). Lower ginger yields have a variety of causes, with illnesses being one of the main contributors to the decline in yield. A significant amount of ginger rots every year as a result of storage illnesses such storage rot or rhizome rot, in addition to many field infections. Post-harvest losses in ginger are a severe worry since after 7-8 months of arduous labor, the priceless crop is lost owing to carelessness in crop production and storage in open piles and underground pits at various phases. There are numerous biotic and abiotic factors that contribute to post-harvest losses. Within three to four weeks of storage, the soft rhizomes were infected with fungus (at a rate of 50%). According to Mitra and Subramaniam (1928), *Pythium* sp., *Fusarium oxysporum* f.sp. *Zingiberi*, and *Sclerotium rolfsii* were the three fungi responsible for storage rot of ginger, with *Fusarium oxysporum* having the highest frequency of occurrence (50%) in storage pits and heaps. Despite the fact that a number of fungal pathogens have occasionally been linked to the disease (Mitra and Subramaniam, 1928), *Pythium* and *Fusarium* species are more common and frequently cause severe crop damage. Fresh produce, including fruits, vegetables, and spices, is a valuable agricultural product that may be utilized for a variety of tasks in both raw and processed forms. In general, fresh ginger is perishable and needs careful handling during storage to maintain freshness. Fresh produce post-harvest marketing, transportation, and storage are all impacted by a number of variables, including storage conditions like temperature, moisture, saprobes assaults, and the lack of storage facilities (Olaimat and Holley, 2012; Wani et al., 2014). Numerous bacterial, fungal, and other microorganism strains look for openings to contaminate ginger,

rendering it unfit for human consumption. The rate of decay and deterioration of ginger is somewhat reduced by coating and fumigation, although customers may not value these practices due to worries about potential health effects. Since ginger must be harvested from parent plants to undergo changes in its metabolic activities, managing post-harvest diseases in ginger is a difficult task (Ullah et al. 2016). However, by directing these activities in the right direction by using the right mechanism, quality and durability may be maintained. When chemicals are used, residues build up on the ginger. Consumer health suffers as a result of the chemical residue on ginger's surface (Tripathi et al., 2008). Toxic side effects include carcinogenicity, teratogenicity, and other genotoxic qualities may result from the excessive use of chemicals as antifungal agents, according to Basilico and Basilico (1999). Additionally, unchecked use of such chemicals results in eco-hazardous effects and increases pathogen resistance to these fungicides (Brent and Hollomon, 1995). Therefore, alternative approaches that are eco-friendly for both humans and the environment should be preferred for the management of post-harvest diseases in ginger. One of these methods is gamma irradiation, which has been approved for use by the International Atomic Energy Agency (IAEA) for the processing and storage of fresh fruits, vegetables, juices, and other food products at doses below 10 kGy (Allothman et al., 2009). Gamma irradiation involves subjecting materials to gamma rays, a kind of extremely intense electromagnetic waves with a remarkable capacity for penetrating deeply into materials. Gamma irradiation is frequently utilized in agriculture due to its high penetrability to prevent microbial deterioration of agricultural products and to potentially cause beneficial mutations in plants (Silva, 2012). Vegetable growth, production, and post-harvest storage need to be improved in order to provide a healthy diet to the expanding human population. Vegetables are a significant part of the human diet. Similar losses are caused by post-harvest rot of ginger due to microbial attack during storage, which may be successfully managed by the use of gamma irradiation (Majeed et al., 2017). In earlier experiments, ascorbic acid levels rose in celery, cabbage, and lettuce whereas carrots and cucumbers maintained their levels of carotenoids and vitamin C at doses between 1 and 2 kGy (Bandeekar et al., 2006). At a dose of 0.5 kGy, Prakash et al. (2002) found a significantly lower microbial count of spoilage fungi in tomatoes without any unacceptably negative changes to the tomatoes' chemical, sensory, or quality parameters. According to Jiang et al. (2010), 20 days of storage of irradiated mushrooms revealed firmness and a high level of antioxidant activity at 1.0 kGy. Fresh mint irradiated with 0.25–1 kGy showed improved chlorophyll concentrations, sensory quality, and visual quality while having a lower microbial burden, according to (Hsu et al., 2010). As a result of pre-storage treatment Gamma irradiation, with doses

ranging from 50 to 150 Gy, has been found to reduce sprouting, specific gravity, and weight loss in ginger while improving its shelf life (Rezaee et al., 2011). Similarly, Mahto and Das (2014) observed that gamma irradiation doses of 0.04-1 kGy reduced sprouting and enhanced the textural properties of ginger. Iqbal et al. (2013) demonstrated that 6 kGy radiation treatments significantly decreased fungus load and aflatoxins in red chilies. Browning in cabbage was effectively minimized with a 2 kGy irradiation treatment (Banerjee et al., 2015). Guerreiro et al. (2016) showed that 3 kGy irradiation extended the shelf life and improved the quality of cherry tomatoes stored at 4°C for 14 days. Fresh fruits and vegetables, including ginger, undergo biochemical and physiological changes after detachment from the plant, which can affect their shelf life and sensory qualities (Reyes and Cisneros-Zevallos, 2007; Ahmad and Siddiqui, 2015). Ionizing radiation generates reactive oxygen species, which can mitigate oxidative stress and prolong the shelf life of fresh produce (Kumar et al., 2014). Gamma radiation can effectively control spoilage microorganisms, inhibiting their growth and extending the storage life of ginger (El-Sherif et al., 2011; Kumar et al., 2014; Shahbaz et al., 2014). This study aimed to evaluate the efficacy of Gamma irradiation in preventing ginger rhizome rot during storage and extending the shelf life of fresh ginger rhizomes under different storage conditions.

MATERIALS AND METHODS

Experimental site and climate

The experiment was conducted between September 2021 and April 2022, with a storage phase from October 2021 to January 2022. It followed a Completely Randomized Design (CRD) with three replications and was conducted at the Division of Plant Pathology, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh. The local cultivar Rangpuri was used, sourced from Natun Bazar, Mymensingh Sadar, Mymensingh. Only good quality rhizomes of similar size were selected, with a total of 81 kg of ginger used in the experiment.

Treatments

Nine treatments were considered for the experiment including radiation, bio-agents, and chemicals. Different treatments along with radiation are given below: T0 = Control (without radiation), T1 = 20 Gy, T2 = 40 Gy, T3 = 60 Gy, T4 = 300 Gy, T5 = 500 Gy, T6 = 700 Gy, T7 = Dithane M-45 (Mancozeb), T8 = Trichoderma. Three types of containers were used to store ginger for the experiment. They were Brown paper, Gunny bag and Polythene bag. At 10 July, 2021 these containers were collected from the market and prepared for storing through cutting and sewing.

Irradiation of Zinger

In October 3, 2021 Ginger rhizome samples were irradiated at Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh with Co60 gamma radiation source machine named: Gamma Irradiator (GC-5000). The rhizomes were exposed as follows: The rhizomes were divided into three replications for each treatment from each container. All the samples from each container were taken into polythene bag and were exposed to 20Gy, 40Gy, 60Gy, 300Gy, 500Gy, 700 Gy separately (Fig.1).



Figure 1. Gamma irradiated ginger rhizomes stored on Brown paper, in Gunny bag and Poly bag.

Preparation of chemicals and bioagents

Before the start of the disease, dithane-M45 was sprayed on in a stored state. A paste was created by combining 4 grams of fungicide with a bit of water. To which 1 L of water is added and mixed thoroughly. BINA Trichoderma (*Trichoderma asperellum*) was grown on PDA plate. After 4-5 days fungal mycelium was blended with 500 ml of Water. The solution was filtered through the cheese cloth. The filtered solution was poured into the spray bottle (Seng et al., 2014).

Isolation and identification of causal organisms associated with Ginger rhizome

Preparation of PDA media

Potato Dextrose Agar (PDA) was used throughout the research work to prepare the inoculum of *Fusarium oxysporum* causing storage rot of Zinger. For isolation by incubation of associated mycoflora, acidified Potato Dextrose Agar (PDA) was used throughout the work period. For each 9 dia. petridishes about 20-25ml of the medium was used. 32 drops of 50% lactic acid were added to the medium to make it acidic. On slants of PDA, test tube stock cultures of the isolates were kept.

Isolation of fungi

For isolation, ginger rhizomes that were not completely rotten but clearly exhibited disease symptoms were chosen. In order to eliminate soil and sand particles, a few sick Zinger rhizomes were extensively washed in running tap water. After being surface sterilized for 60 seconds with a solution of 1% sodium hypochlorite, the bulbs were washed three times in sterile distilled water. Samples were sliced and placed on a PDA plate after they had dried on blotter

paper. For one week, culture plates were incubated at (25–27)°C. Fungal growth was seen after 7 days of incubation, and the pathogens were then moved on fresh PDA plates. For the purpose of maintaining sterility, all of these procedures were carried out in a laminar air flow chamber. Mycelia fragments were placed in minute pieces to PDA plates (Fig. 2). By moving the fungus block to fresh PDA plates, subcultures were created. The fungi were recognized by looking at the characteristics of the colonies, linear growth, medium color, and sporulation (Singh, 1982).

Identification of fungi

In order to document the presence of fungi, each diseased Zinger rhizome sample (with petridish) was examined using a stereomicroscope at 10X and 40X magnifications. Following the guidelines provided by Barnett (1965), the majority of the related bacteria were found by studying their development characteristics on the diseased Zinger rhizomes that had been incubated on PDA. Temporary slides from the fungal colony were made for the purpose of confirming the identification of fungi. These slides were then examined under a compound microscope and identified using the keys proposed by Booth (1971) and Ellis (1971).

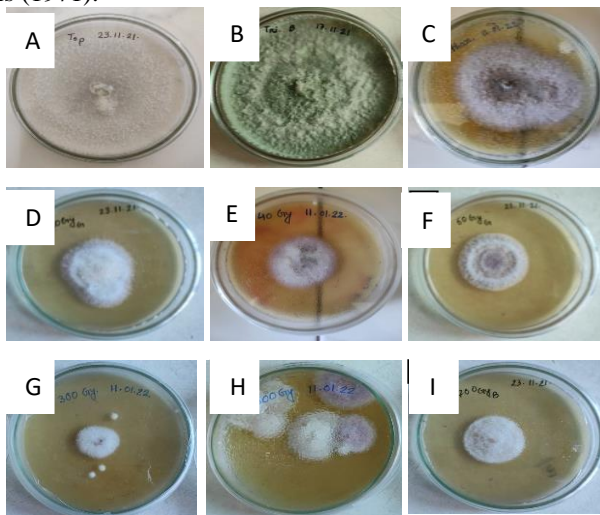


Figure 2. Isolation of different organisms from different treatments on PDA plates

A= 0 Gy(Control), B= Trichoderma, C= Dithane M-45, D= 20 Gy, E= 40 Gy, F= 60 Gy, G= 300 Gy, H= 500 Gy, I= 700 Gy

Pathogenicity test

Pathogenicity test of the isolates was done to be certain about the disease causal organisms. Healthy and diseased free Zinger rhizomes were selected for inoculation without injury. The rhizomes were not pricked just cut into slices and inoculums were placed onto the surface of the slices with sterilized needle. The test Rhizomes were then incubated at 26°C for up to 14 days. After inoculation, the inoculated and control rhizomes were stored for 14 days into incubation chamber and were allowed for disease development. Data were collected at 3 days intervals up to

15 days. The disease was recorded by eye estimation of the inoculated stored rhizomes.

Gamma Irradiation on isolated fungus

Gamma irradiation was exposed to isolated fungal pathogen to observe effect on fungal mycelia growth. By transferring a fungal block from a pure culture to fresh PDA plates, sub-cultures were created. At 26°C, the plates were incubated. At the Electronics & Health Physics division of the Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, the samples were exposed to gamma radiation with seven doses, including 0 Gy (Control), 20 Gy, 40 Gy, 60 Gy, 300 Gy, 500 Gy, and 700 Gy. The sample preparations were stored at ambient temperature (25–27 °C). The radial measurement of growth was kept track of daily until the fungus reached the plate's edge. Two copies of each treatment were performed. For the comparison of mycelial growth in the Control plate and exposed to gamma irradiation from a cobalt 60 source at different doses, i.e. (20, 40, 60, 300, 500, 700) Gy, the percentage of mycelia growth was computed (Patil, 2004).

Dual culture assay of BINA Trichoderma against Fusarium oxysporum

Dual culture approach was used to assess BINA Trichoderma's relative viability against Fusarium oxysporum. A test growth circle measuring about 1 cm in diameter and the hostile organism, which was scraped off the edge of a five-day-old culture, were placed opposite to one another at a distance of 5 cm from the edge of the petri plate. Another petri plate containing the same test organism was placed on top of a PDA dish, which served as the control. Three copies of each therapy were made and kept between 26 and 28 degrees Celsius. After 7 days, the plates underwent analysis to look for the emergence of Trichoderma and pathogen resistance zones.

Percent growth inhibition was calculated by using the following formula (Harman et al., 2012):

$$I = \frac{C - T}{C} \times 100$$

Where:

I = Inhibition of radial mycelia growth

C = Radial growth measurement of the fungus in the control plate

T = Radial growth measurement of the pathogen in the dual cultured plate

Poison food technique

Using the approach of poisoned food, the fungicide DithaneM-45's effectiveness against Fusarium oxysporum was assessed. The basic idea behind this method is to add a harmful chemical to the nutrient medium before letting a test fungus to develop on it. The effectiveness of the poisonous chemical is then assessed by tracking the fungus's growth (Sasikumar et al., 2009). By taking the active components, the fungicide's dilution was made. The percentage of the product's active ingredient was taken into

account while calculating the actual quantity of the pharmaceutical product used in this study. The diluted fungicide was then incorporated and mixed well in conical flask containing PDA media sterilized by an autoclave at about 50°C and poured 20ml in each petridish of 9cm diameter. Stock solution was prepared by taking 0.04gm DithaneM-45 into 100 ml distilled water (Gupta, 1993).
 For 0.75% solution, 75ml stock solution + 25 ml PDA
 For 1% solution, 100 ml PDA + 0.04 gm DithaneM-45
 For 2% solution 100ml PDA + 0.08 gm DithaneM-45

Inoculation with test organism

Disks 1 cm in diameter were cut from a fungus culture that was actively growing and put aseptically into the center of a Petridis that contained the test media using a sterile cork borer. Three replicates were kept, one of which was the control (chemical-free). The inoculated petri dishes were incubated at 26–28°C, and after the first, third, and fifth days, the fungal diameter was determined.

Data record

Data on different parameters (viz. Sprouting, disease incidence, disease severity, fungal mycelium growth rate, moisture and temperature of the storage room) were recorded from time to time during the tenure of the work for requisite parameter.

Sprouting percentage

Total number of rhizomes and number of sprouted rhizomes present in each replication of the three different lots (Brown paper, Gunny bag, and Poly bag) were recorded and the sprouting percentage was calculated by using the following formula (Sharma, 2004):

$$\text{Sprouting (\%)} = \frac{\text{Number of sprouted rhizomes}}{\text{Total number of rhizomes}} \times 100$$

Disease incidence and severity

Disease incidence level was recorded as the percentage of infected rhizomes in each sample using the following formula (Habib et al., 2011):

$$\text{Disease incidence} = \frac{\text{Number of infected rhizomes}}{\text{Total number of rhizomes}} \times 100$$

Infected area and total area of the infected rhizomes were recorded then disease severity was calculated by the following formula (Habib et al., 2011):

$$\text{Disease severity} = \frac{\text{infected area of the infected rhizomes}}{\text{Total area of infected rhizomes}} \times 100$$

Experimental design and statistical analysis

Using the STATISTICS-10 package application, the experiment's data on numerous parameters were statistically evaluated to determine the variation brought on by the experimental treatments. The 5% level of probability used in the LSD test to determine the significance of the

difference between the two means (Gomez and Gomez, 1984).

RESULTS

Identification of causal organism associated with storage rot of ginger rhizome

Microscopy was used to pinpoint the etiological agent of the ginger storage rot. A lot of white cottony mycelium and a dark-purple undersurface on PDA were characteristics of colonies (Fig. 3A, B). Macroconidia had three septated cells and were oval-shaped with a sickle-shaped tip. Oval to ellipsoid or kidney-shaped microconidia were seen (Fig. 3C). Hyphae were septate, hyaline, and branching at acute angles (Fig. 3 D).

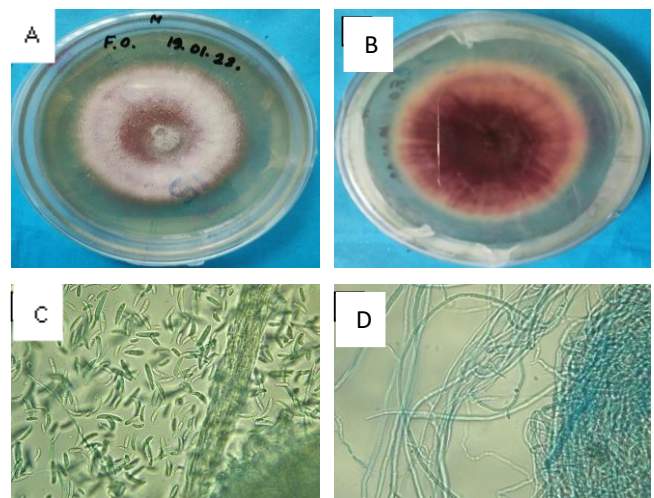


Figure 3. Colony characters of *Fusarium oxysporum*. A. White cottony mycelium, B. Dark purple under surface C. oval shaped microconidia & sickle shaped macroconidia D. Fungal mycelia.

Pathogenicity test of *Fusarium oxysporum* on ginger rhizome

In the inoculation test, sliced (cut surface) rhizomes tested positive for the fungi *Fusarium oxysporum*. White fungal mycelium was observed on the rhizome slice after 14 days of inoculation.

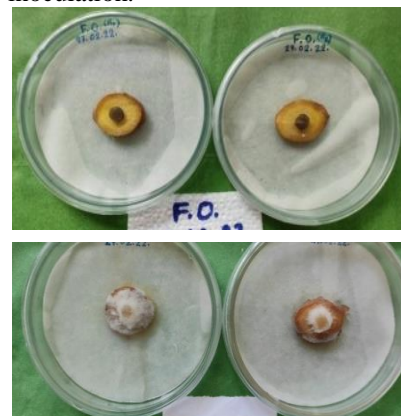


Figure 4: Mycelia of *Fusarium oxysporum* on Ginger slice under pathogenicity test. A. Ginger slice inoculated with *F. oxysporum* B. Mycelia grown on sliced ginger

Effect of Gamma Irradiation on sprouting of Ginger rhizome at different storage conditions at 30, 60 and 90 days after storage

At 30 days after storage

Effect of Gamma irradiation on sprouting of Ginger rhizome differed significantly among the different storage condition (on brown paper, in Gunny bag and poly bag) after 30 days of storage are shown in Table 1. On Brown paper, the lowest sprouting 0.00% was recorded in 60Gy, 300Gy, 500Gy and 700Gy and the highest in Trichoderma treated sample compared to control. Sprouting percentage of chemical fungicide treated sample was close to control sample. The sprouting percentage in Trichoderma treated samples was 15.89% and in untreated control sample was 6.22% and in DithaneM-45 treated sample was 6.28%. In Gunny bag, the lowest sprouting 0.00% was recorded in 60Gy, 300Gy, 500Gy and 700Gy and the highest in Trichoderma treated sample compared to control. Sprouting percentage of chemical fungicide treated sample was close to control. The sprouting percentage in Trichoderma treated sample was 7.85% and in untreated control sample was 7.50% and in DithaneM-45 treated sample was 4.75%. In case of Poly bag, the lowest sprouting 0.00% was recorded in 60Gy, 300Gy, 500Gy and 700Gy and the highest in DithaneM-45 treated sample other than Trichoderma treated sample which were recorded higher in Brown paper and Gunny bag. The sprouting percentage in DithaneM-45 treated sample was 19.86% in untreated control sample was 11.24% and in Trichoderma treated sample was 7.60%. Up to 100% inhibition of sprouting was recorded in 60Gy, 300Gy, 500Gy and 700Gy treated samples in all the three containers (Brown paper, Gunny bag and Poly bag) over control. (Fig. 6)

At 60 days after storage

Effect of Gamma irradiation on sprouting of Ginger rhizome differed significantly among the different storage condition (on Brown paper, in Gunny bag and Poly bag) after 60 days of storage are shown in Table 1. On Brown paper, the lowest sprouting 0.00% was recorded in 60Gy, 300Gy, 500Gy and 700Gy and the highest in Trichoderma treated sample compared to control. Sprouting percentage of chemical fungicide treated sample was close to control sample. The sprouting percentage in Trichoderma treated sample was 27.94% and in untreated control sample was 16.33% and in DithaneM-45 treated sample was 15.45%. In Gunny bag, the lowest sprouting 0.00% was recorded in

60Gy, 300Gy, 500Gy and 700Gy and the highest in Trichoderma treated samples compared to control. Sprouting percentage of chemical fungicide treated samples was close to control. The sprouting percentage in Trichoderma treated samples was 25% and in untreated control sample was 23.34% and in DithaneM-45 treated sample was 18.39%. In case of Poly bag, the lowest sprouting 0.00% was recorded in 60Gy, 300Gy, 500Gy and 700Gy and the highest in DithaneM-45 treated sample other than Trichoderma treated sample which was recorded higher in Brown paper and Gunny bag. The sprouting percentage in DithaneM-45 treated sample was 42.84% in untreated control samples was 29.37% and in Trichoderma treated sample was 2.46%. Up to 100% inhibition of sprouting was recorded in 60Gy, 300Gy, 500Gy and 700Gy treated samples in all the three containers (Brown paper, Gunny bag and Poly bag) over control. (Fig. 7)

At 90 days after storage

Effect of Gamma irradiation on sprouting of Ginger rhizome differed significantly among the different storage condition (on brown paper, in Gunny bag and poly bag) after 90 days of storage are shown in Table 1. On Brown paper, the lowest sprouting 0.00% was recorded in 60Gy, 300Gy, 500Gy and 700Gy and the highest in Trichoderma treated sample compared to control. Sprouting percentage of chemical fungicide treated sample was close to control sample. The sprouting percentage in Trichoderma treated sample was 41.15% and in untreated control sample was 26.46% and DithaneM-45 treated sample was 23.87%. In Gunny bag, the lowest sprouting 0.00% was recorded in 60Gy, 300Gy, 500Gy and 700Gy and the highest in Trichoderma treated sample compared to control. Sprouting percentage of chemical fungicide treated sample was close to control sample. The sprouting percentage in Trichoderma treated sample was 36.33% and in untreated control sample was 36.66% and in DithaneM-45 treated sample was 30.78%. In case of Poly bag, the lowest sprouting 0.00% was recorded in 60Gy, 300Gy, 500Gy and 700Gy and the highest in DithaneM-45 treated samples other than Trichoderma treated sample which was recorded higher in Brown paper and Gunny bag. The sprouting percentage in DithaneM-45 treated sample was 52.75% in untreated control sample was 47.48% and in Trichoderma treated sample was 38.30%. Up to 100% inhibition of sprouting was recorded in 60Gy, 300Gy, 500Gy and 700Gy treated samples in all the three containers (Brown paper, Gunny bag and Poly bag) over control (Fig. 8).

Table-1: Effect of Gamma irradiation on sprouting of Ginger at 30, 60 & 90 days after storage on Brown paper, Gunny and Polybag.

Treatment	Sprouting (%)								
	Brown paper			Gunny bag			Poly bag		
	30days	60days	90days	30days	60days	90days	30days	60days	90days
0Gy (Control)	6.22b	16.33b	26.46b	7.50a	23.34ab	36.66a	11.24b	29.37ab	47.48ab
20 Gy	4.36b	5.74c	13.91bc	3.92b	5.61c	11.13b	7.32bc	16.16bcd	27.77bc

40 Gy	2.48bc	3.33c	4.96c	2.79bc	3.92c	7.02bc	4.94bc	5.35cd	8.62cd
60 Gy	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00d	0.00d
300 Gy	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00d	0.00d
500 Gy	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00d	0.00d
700 Gy	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00c	0.00d	0.00d
DithaneM-45	6.28b	15.45b	23.87b	4.75ab	18.39b	30.78a	19.86a	42.84a	52.75a
Trichoderma	15.89a	27.94a	41.15a	7.85a	25.00a	36.33a	7.60bc	20.46bc	38.30ab
CV (%)	1.82	3.29	4.55	6.20	7.29	9.00	3.63	4.99	8.01
LSD (0.05)	1.14	1.51	2.19	1.16	1.95	2.02	1.24	1.98	3.09
SE	0.38	0.51	0.74	0.39	0.65	0.75	0.42	0.67	1.04

In column, figures with similar letter do not differ significantly where figures with dissimilar letter differ significantly. CV = Coefficient of variance, LSD = Least Significance Difference, SE = Standard Error

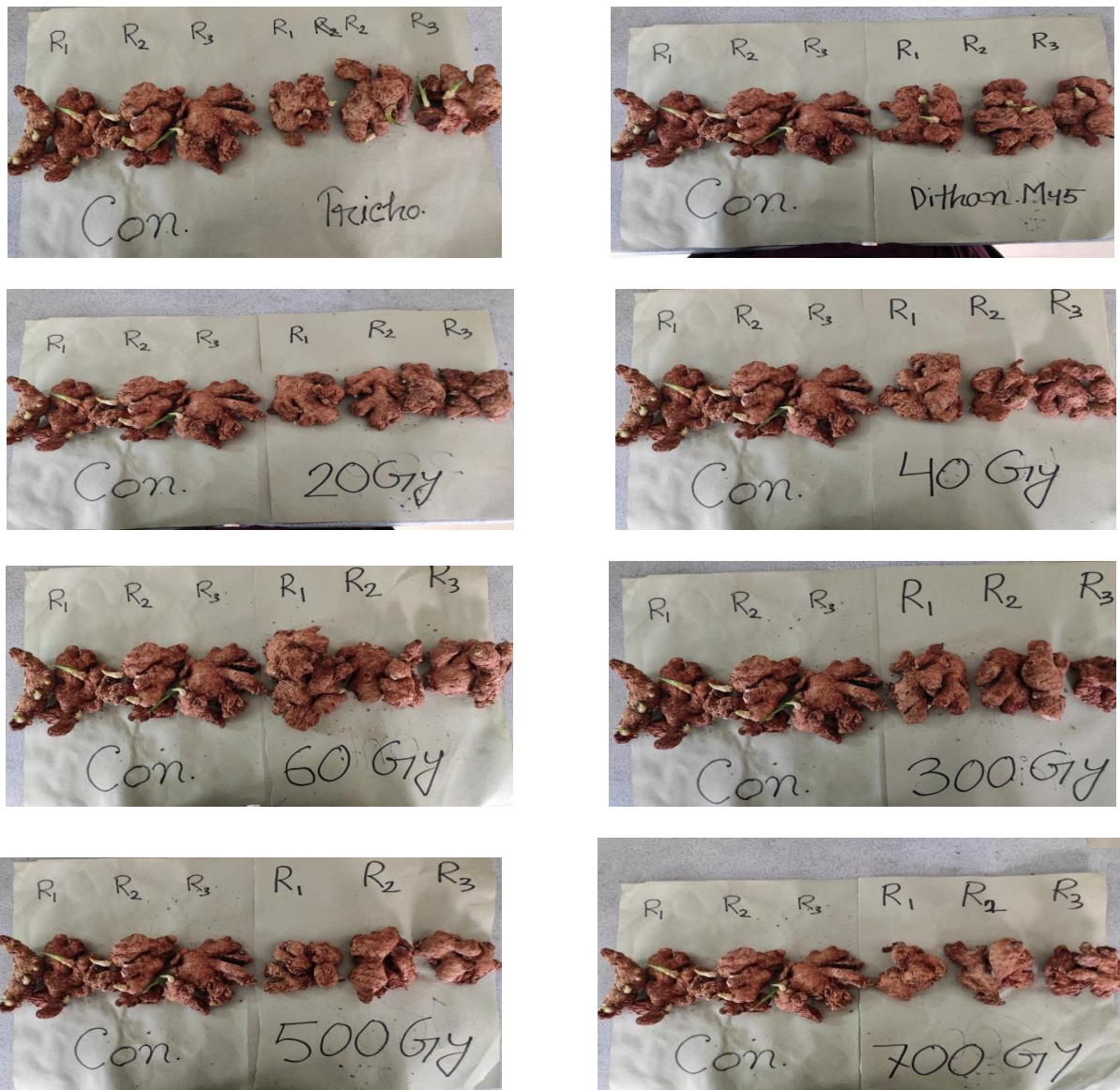
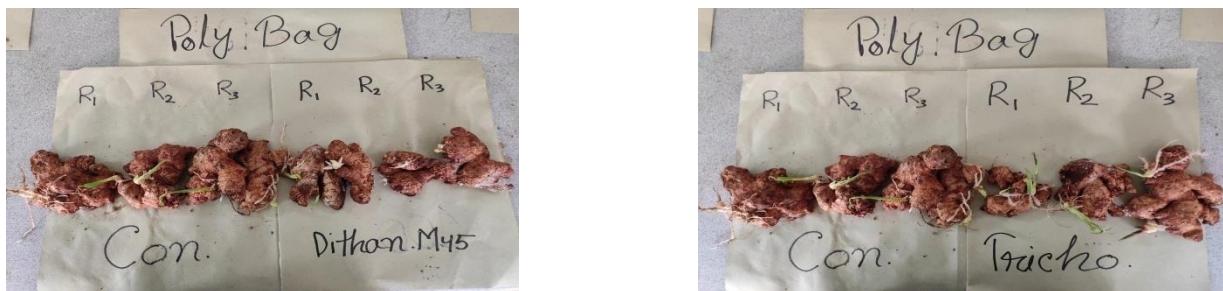


Figure 6: Effect of Gamma irradiation, chemical fungicide and bio-fungicide on sprouting of Ginger after 3 months of storage on Brown paper



Figure 7: Effect of Gamma irradiation, chemical fungicide and bio-fungicide on sprouting of Ginger after 3 months of storage in Gunny bag.



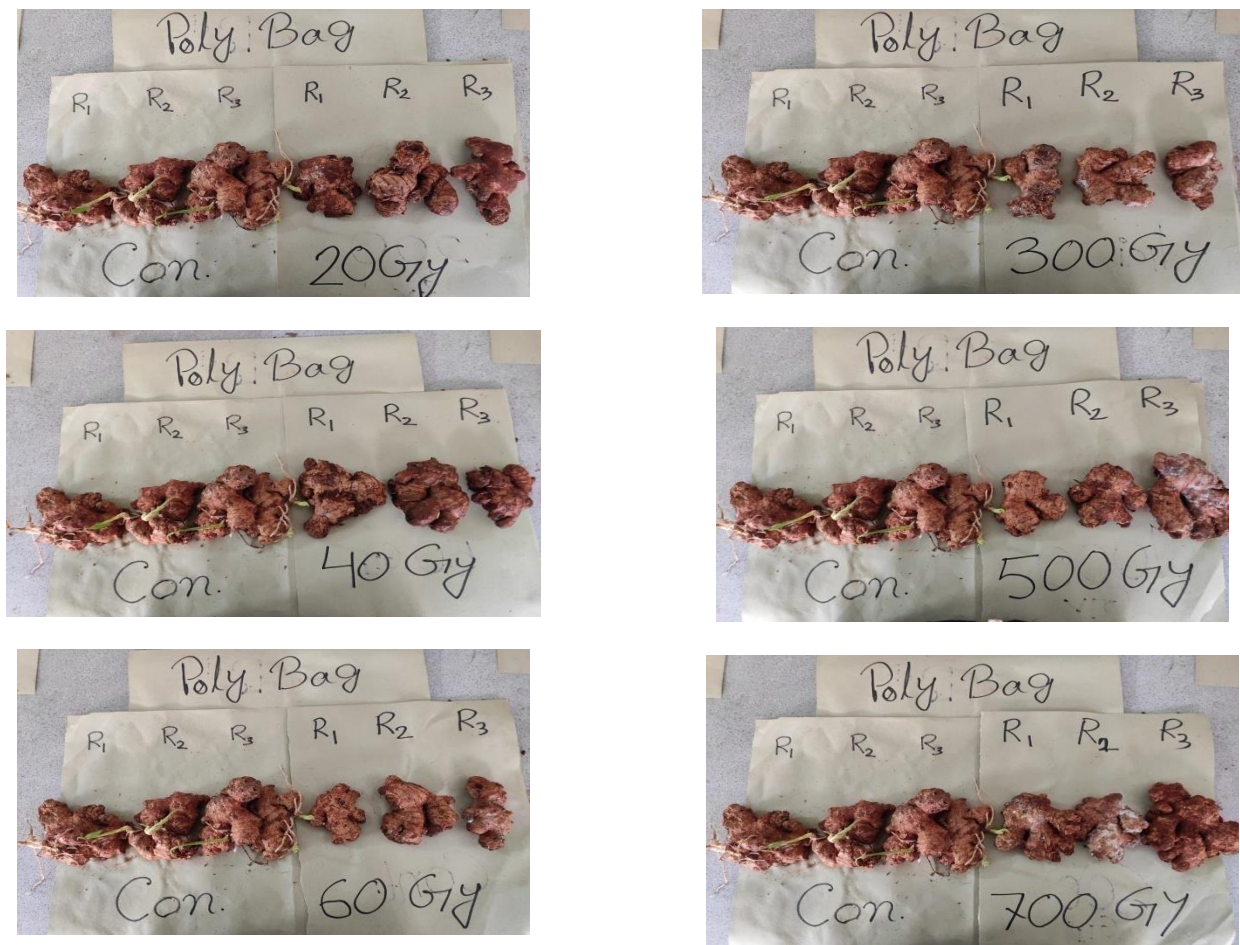


Figure 8: Effect of Gamma irradiation, chemical fungicide and bio-fungicide on sprouting of Ginger after 3 months of storage in Poly bag

Effect of Gamma Irradiation on storage rot disease incidence of Ginger rhizome on different storage conditions at 30, 60 and 90 days after storage

At 30 days after storage

Effect of Gamma irradiation on storage rot disease incidence of Ginger rhizome differed significantly among the different storage conditions (Brown paper, Gunny bag and Poly bag) after 30 days of storage are shown in Table 2. On Brown paper, disease incidence was significantly decreased with increased gamma irradiation. The lowest storage rot incidence 11.67% was recorded in case of using 700Gy of irradiation followed by 500Gy-11.67%, 300Gy-15.06%, 60Gy-20.03%, 40Gy-33.33%, 20Gy-36.17%. DithaneM-45 and *Trichoderma* showed 15.06% and 11.67% respectively and the highest disease incidence was recorded in untreated or control sample 41.67%. In Gunny bag, disease incidence was significantly decreased with increased gamma irradiation. The lowest storage rot incidence 23.33% was recorded in

case of using 700Gy of irradiation followed by 500Gy-30%, 300Gy-33.33%, 60Gy-36.67%, 40Gy-40.03%, 20Gy-44.67%. DithaneM-45 and *Trichoderma* showed 30.03% and 26.17% respectively and the highest disease incidence was recorded in untreated or control sample 48.10%. In case of Poly bag, storage rot incidence was significantly decreased in DithaneM-45 treated sample over untreated control sample. Among irradiated and bio-fungicide treated samples significant decrease was recorded almost similar in 700Gy & *Trichoderma* treated samples. The lowest disease incidence was recorded in DithaneM-45 treated sample 23.33%. In 700Gy treated sample was 28.33% followed by 500Gy-31.67%, 300Gy-38.33%, 60Gy-38.83%, 40Gy-40.03%, 20Gy-43.33%, in *Trichoderma* treated samples was 28.56% and the highest disease incidence was recorded in untreated or control sample 45.10%. On Brown paper, up to 71.99%, 71.99%, 63.86% decrease of storage rot incidence were recorded for 700Gy, *Trichoderma* &

DithaneM-45 treated samples respectively over control. In Gunny bag, up to 51.49%, 45.59%, 37.57% decrease of storage rot incidence were recorded for 700Gy, *Trichoderma* & DithaneM-45 treated samples respectively over control. In Poly bag, up to 48.27%, 28.33%, 28.56% decrease of storage rot incidence was recorded for & DithaneM-45, 700Gy & *Trichoderma* treated samples respectively over control

At 60 days after storage

Effect of Gamma irradiation on storage rot disease incidence of Ginger rhizome differed significantly among the different storage conditions (on Brown paper, Gunny bag and Poly bag) after 60 days of storage are shown in Table 2. On Brown paper, disease incidence was significantly decreased with increased gamma irradiation. The lowest storage rot incidence 42.62% was recorded in case of using 700Gy of irradiation followed by 500Gy-46.13%, 300Gy-48.44%, 60Gy-50.80%, 40Gy-51.67%, 20Gy-53.33%. DithaneM-45 and *Trichoderma* showed 51.67% and 43.76% respectively and the highest disease incidence was recorded in untreated or control sample 53.33%. In Gunny bag, disease incidence was significantly decreased with increased gamma irradiation. The lowest storage rot incidence 43.58% was recorded in case of using 700Gy of irradiation followed by 500Gy-47.68%, 300Gy-49.26%, 60Gy-51.59%, 40Gy-52.20%, 20Gy-52.31%. DithaneM-45 and *Trichoderma* showed 48.87% and 47.62% respectively and the highest disease incidence was recorded in untreated or control sample 53.70%. In case of Poly bag storage rot incidence was significantly decreased in DithaneM-45 treated samples over untreated control sample. Among irradiated and bio-fungicide treated samples significant decrease was recorded in 700Gy. The lowest disease incidence was recorded in DithaneM-45 treated sample 49.01%. In 700Gy treated sample was 51.86% followed by 500Gy-54.21%, 300Gy-54.63%, 60Gy-55.92%, 40Gy-58.83%, 20Gy-59.64% in *Trichoderma* treated sample was 52.67% and the highest disease incidence was recorded in untreated or control sample 60.94%.

At 90 days after storage

Effect of Gamma irradiation on storage rot disease incidence of Ginger rhizome differed significantly among the different storage conditions (Brown paper, Gunny bag and Poly bag) after 90 days of storage are shown in Table 2. On Brown paper, disease incidence was significantly decreased with increased gamma irradiation. The lowest storage rot incidence 56.83% was recorded in case of using 700Gy of irradiation followed by 500Gy-68.77%, 300Gy-69.33%, 60Gy-69.81%, 40Gy-74.16%, 20Gy-88.27%. DithaneM-45 and *Trichoderma* showed 66.72% and 61.04% respectively and the highest disease incidence was recorded in untreated or control sample 88.41%. In Gunny bag, disease incidence was significantly decreased with increased gamma irradiation. The lowest storage rot incidence 68.15% was recorded in case of using 700Gy of irradiation followed by 500Gy-79.07%, 300Gy-79.88%, 60Gy-80.53%, 40Gy-81.00%, 20Gy-84.17%. DithaneM-45 and *Trichoderma* showed 79.00% and 72.88% respectively and the highest disease incidence was recorded in untreated or control sample 90.67%. In case of Poly bag, after 90 days of storage all the samples in all the treatments showed almost 100% disease incidence. The lowest incidence recorded in DithaneM-45 treated samples was 82.65%. Among the irradiated and bio-fungicide treated samples lowest incidence was recorded in 700Gy treated sample 87.89% followed by 500Gy-91.35%, 300Gy-96.67%, 60Gy-100%, 40Gy-100%, 20Gy-100% and in *Trichoderma* treated samples was 90.87%. On Brown paper, up to 35.72%, 32.19%, 24.53% decrease of storage rot incidence were recorded for 700Gy, *Trichoderma* & DithaneM-45 treated samples respectively over control.

In Gunny bag, up to 24.83%, 12.87%, 19.62% decrease of storage rot incidence were recorded for 700Gy, *Trichoderma* & DithaneM-45 treated samples respectively over control. In Poly bag, up to 17.35%, 12.11%, 9.13% decrease of storage rot disease incidence was recorded for DithaneM-45, 700Gy, & *Trichoderma* treated samples respectively over control.

Table 2: Effect of Gamma irradiation on storage rot incidence of Ginger after 30, 60 and 90 days of storage on Brown paper, Gunny and Polybag.

Treatments	Disease Incidence (%)								
	Brown paper			Gunny bag			Poly bag		
	30days	60days	90days	30days	60days	90days	30days	60days	90days
0Gy (Control)	41.67a	53.33ab	88.41a	48.10a	53.70a	90.67a	45.10a	60.94a	100a
20 Gy	36.17b	53.33ab	88.27a	44.67b	52.31ab	84.17b	43.33b	59.64ab	100a
40 Gy	33.33c	51.67bc	74.16b	40.03c	52.20ab	81.00cd	40.03c	58.83b	100a

60 Gy	20.03d	50.80c	69.81c	36.67d	51.59b	80.53cde	38.83c	55.92cd	100a
300 Gy	15.06e	48.44d	69.33cd	33.33e	49.26c	79.88de	38.33c	54.63d	96.67b
500 Gy	11.67f	46.13e	68.77cd	30.00f	47.68c	79.07e	31.67d	54.21d	91.35c
700 Gy	11.67f	42.62f	56.83g	23.33h	43.58d	68.15g	28.33e	51.86ef	87.89d
Dithane M-45	15.06e	51.67bc	66.72e	30.03f	48.87c	79.00e	23.33f	49.01f	82.65e
Trichoderma	11.67f	43.76f	61.04f	26.17g	47.62c	72.88c	28.56e	52.67e	90.87c
CV (%)	4.36	1.92	1.37	2.84	1.99	1.45	2.78	1.85	1.99
LSD (0.05)	2.05	2.04	2.55	1.69	2.21	1.02	2.11	2.12	2.50
SE	0.78	0.97	1.21	0.80	1.01	1.01	1.69	0.80	1.50

In column, figures with similar letter do not differ significantly where figures with dissimilar letter differ significantly.

Effect of Gamma Irradiation on storage rot disease severity of Ginger rhizome on different storage conditions at 30, 60 and 90 days after storage

At 30 days after storage

Effect of Gamma irradiation on storage rot disease severity of Ginger rhizome differed significantly among the different storage conditions (Brown paper, Gunny bag and Poly bag) after 30 days of storage are shown in Table 3. On Brown paper, disease severity was significantly decreased with increased gamma irradiation. The lowest storage rot severity 15.05% was recorded in case of using 700Gy of irradiation followed by 500Gy-21.67%, 300Gy-25.06%, 60Gy-30.03%, 40Gy-42.33%, 20Gy-46.17%. DithaneM-45 and Trichoderma showed 20.67% and 16.89% respectively and the highest disease severity was recorded in untreated or control sample 51.67%. In Gunny bag, disease severity was significantly decreased with increased gamma irradiation. The lowest storage rot severity 28.00% was recorded in case of using 700Gy of irradiation followed by 500Gy-35.03%, 300Gy-42.33%, 60Gy-46.67%, 40Gy-50.06%, 20Gy-54.67%. DithaneM-45 and Trichoderma showed 41.05% and 33.33% respectively and the highest disease severity was recorded in untreated or control sample 58.15%. In case of Poly bag storage rot severity was significantly decreased in DithaneM-45 treated samples over untreated control samples. Among irradiated and bio-fungicide treated samples significant decrease was recorded in 700Gy treated samples. The lowest disease severity recorded in DithaneM-45 treated samples was 33.33%. In 700Gy treated samples was 38.03% followed by 500Gy-39.67%, 300Gy-45.33%, 60Gy-44.83%, 40Gy-48.69%, 20Gy-51.33%, in Trichoderma treated samples was 40.56% and the highest disease severity recorded in untreated or control samples was 55.10%. On Brown paper, up to 70.87%, 67.31%, 59.99% decrease of storage rot disease severity were recorded for 700Gy, Trichoderma & DithaneM-45 treated samples respectively over control. In Gunny bag, up to 51.85%, 42.68%, 29.40% decrease of storage rot disease severity were recorded for 700Gy, Trichoderma & DithaneM-45 treated samples respectively over control. In Poly bag, up to 39.51%, 30.98%, 26.38% decrease of storage rot disease severity was recorded for DithaneM-45, 700Gy & Trichoderma treated samples respectively over control.

At 60 days after storage

Effect of Gamma irradiation on storage rot disease severity of Ginger rhizome differed significantly among the different storage conditions (Brown paper, Gunny bag and Poly bag) after 60 days of storage are shown in Table 3. On Brown paper, disease severity was significantly decreased with increased gamma irradiation. The lowest storage rot severity 55.87% was recorded in case of using 700Gy of irradiation followed by 500Gy-64.26%, 300Gy-69.25%, 60Gy-70.69%, 40Gy-72.25%, 20Gy-72.31%. DithaneM-45 and Trichoderma showed 60.67% and 60.59% respectively and the highest disease severity was recorded in untreated or control sample 74.70%. In Gunny bag, disease severity was significantly decreased with increased gamma irradiation. The lowest storage rot severity 56.62% was recorded in case of using 700Gy of irradiation followed by 500Gy-61.13%, 300Gy-68.44%, 60Gy-70.80%, 40Gy-72.50%, 20Gy-72.67%. DithaneM-45 and Trichoderma showed 65.89% and 60.76% respectively and the highest disease severity was recorded in untreated or control sample 73.33%. In case of Poly bag storage rot severity was significantly decreased in DithaneM-45 treated samples over untreated control samples. Among irradiated and bio-fungicide treated samples significant decrease was recorded in 700Gy treated samples. The lowest disease severity recorded in DithaneM-45 treated samples was 60.86%. In 700Gy treated samples was 65.67% followed by 500Gy-75.12%, 300Gy-77.63%, 60Gy-79.92%, 40Gy-81.38%, 20Gy-81.63% in Trichoderma treated samples was 68.01% and the highest disease severity recorded in untreated or control samples was 87.94%. On Brown paper, up to 25.20%, 18.89%, 18.51% decrease of storage rot disease severity were recorded for 700Gy, Trichoderma & DithaneM-45 treated samples respectively over control. In Gunny bag up to 22.78%, 17.26%, 10.14% decrease of storage rot disease severity were recorded for 700Gy, Trichoderma & DithaneM-45 treated samples respectively over control. In Poly bag, up to 18.18%, 13.58%, 11.97% decrease of storage rot disease severity was recorded for DithaneM-45, 700Gy & Trichoderma treated samples respectively over control.

At 90 days after storage

Effect of Gamma irradiation on storage rot disease severity of Ginger rhizome differed significantly among the different storage conditions (Brown paper, Gunny bag and

Poly bag) after 90 days of storage are shown in Table 3. On Brown paper, disease severity was significantly decreased with increased gamma irradiation. The lowest storage rot severity 73.31% was recorded in case of using 700Gy of irradiation followed by 500Gy-78.89%, 300Gy-81.25%, 60Gy-86.03%, 40Gy-90.25%, 20Gy-91.13%. DithaneM-45 and Trichoderma showed 80.87% and 78.25% respectively and the highest disease severity was recorded in untreated or control sample 95.50%. In Gunny bag, disease severity was significantly decreased with increased gamma irradiation. The lowest storage rot severity 77.62% was recorded in case of using 700Gy of irradiation followed by 500Gy-81.62%, 300Gy-86.44%, 60Gy-87.19%, 40Gy-91.98%, 20Gy-92.33%. DithaneM-45 and Trichoderma showed 85.89% and 80.90% respectively and the highest disease severity was recorded in untreated or control sample 97.10%. In case of Poly bag, after 90 days of

storage all the samples in all the treatments were showed 100% disease severity except DithaneM-45, 700Gy and Trichoderma treated samples. The disease severity recorded in DithaneM-45 was 87.50%, in 700Gy treated samples was 92.24%, in Trichoderma treated samples was 97.91%. On Brown paper, up to 23.24%, 18.06%, 15.52% decrease of storage rot disease severity were recorded for 700Gy, Trichoderma & DithaneM-45 treated samples respectively over control. In Gunny bag, up to 20.06%, 16.68%, 11.54% decrease of storage rot disease severity were recorded for 700Gy, Trichoderma & DithaneM-45 treated samples respectively over control. In Poly bag up to 11.50%, 8.41%, 2.09% decrease of storage rot disease severity was recorded for DithaneM-45, 700Gy & Trichoderma treated samples respectively over control.

Table 3: Effect of Gamma irradiation on storage rot severity of Ginger after 30, 60 and 90 days of storage on Brown paper, Gunny and Polybag.

Treatments	Disease Severity (%)								
	Brown paper			Gunny bag			Poly bag		
	30days	60days	90days	30days	60days	90days	30days	60days	90days
Control	51.67a	74.70a	95.50a	58.15a	73.33a	97.10a	55.10a	82.94a	100.00a
20 Gy	46.17b	72.31ab	91.13b	54.67b	72.67ab	92.33b	51.33b	81.63ab	100.00a
40 Gy	42.33c	72.25ab	90.25b	50.06c	72.50ab	91.98b	48.69c	81.38ab	100.00a
60 Gy	30.03d	70.69c	86.03c	46.67d	70.80c	87.19c	44.83d	79.92c	100.00a
300 Gy	25.06e	69.25c	81.25d	42.33e	68.44d	86.44c	45.33d	77.63c	100.00a
500 Gy	21.67f	64.26d	78.89e	35.03f	61.13f	81.62d	39.67f	75.12c	100.00a
700 Gy	15.05g	55.87f	73.31f	28.00g	56.62g	77.62e	38.03e	71.67d	92.24c
Dithane M-45	20.67f	60.87e	80.67d	41.05e	65.89e	85.89c	33.33g	67.86e	88.50d
Trichoderma	16.89g	60.59e	78.25e	33.33f	60.76f	80.90d	40.56e	73.01c	97.91b
CV (%)	5.76	2.39	1.98	7.01	3.18	2.91	8.71	2.86	0.00
LSD (0.05)	9.19	15.48	17.15	10.59	9.90	17.47	10.69	14.58	0.00
SE	0.09	5.21	5.77	0.60	3.33	5.88	0.60	4.91	0.00

In column, figures with similar letter do not differ significantly where figures with dissimilar letter differ significantly.

Effect of Gamma irradiation on mycelium growth of Fusarium oxysporum

Effect of Gamma irradiation on mycelium growth of Fusarium oxysporum isolates was recorded in Table-4. After 5 days of irradiation the lowest mycelium growth was

recorded in 700Gy treated samples 5 mm followed by 11.50 mm, 15.50 mm, 18.00 mm, 19.50 mm, 20.50 mm for 500Gy, 300Gy, 60Gy, 40Gy, 20Gy respectively and the highest growth was recorded in untreated or control samples 24.50 mm. As per mean, up to 76.86% decrease in mycelium growth was recorded in 700 Gy treated sample over control. (Fig.9)

Table 4: Effect of Gamma irradiation on mycelium growth of Fusarium oxysporum in PDA.

Treatments	Mycelium growth (mm)					
	1st DAI	2nd DAI	3rd DAI	4th DAI	5th DAI	Mean
0 Gy(Control)	5.00a	11.00a	15.50a	20.50a	24.50a	15.3
20 Gy	4.50ab	10.50a	13.50b	16.50b	20.50b	13.10
40 Gy	3.50bc	8.50b	12.50bc	15.50bc	19.50bc	11.90
60 Gy	3.50bc	8.00b	12.00c	14.50c	18.00c	11.20
300 Gy	2.50cd	5.00c	9.50d	12.50d	15.50d	9.00

500 Gy	2.50cd	3.50d	5.50e	8.50e	11.50e	6.30
700 Gy	2.00d	3.00d	3.70f	4.00f	5.00f	3.54
CV (%)	17.80	6.55	5.82	4.98	4.90	
LSD (0.05)	1.41	1.09	1.42	1.54	1.89	
SE	0.59	0.46	0.60	0.65	0.80	

In column, figures with similar letter do not differ significantly where figures with dissimilar letter differ significantly. DAI = Days After Irradiation,

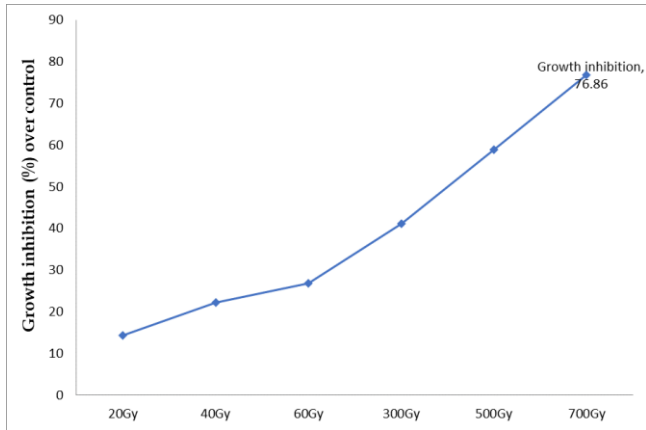


Figure 9: Mycelium growth inhibition (%) of *Fusarium oxysporum* over control.

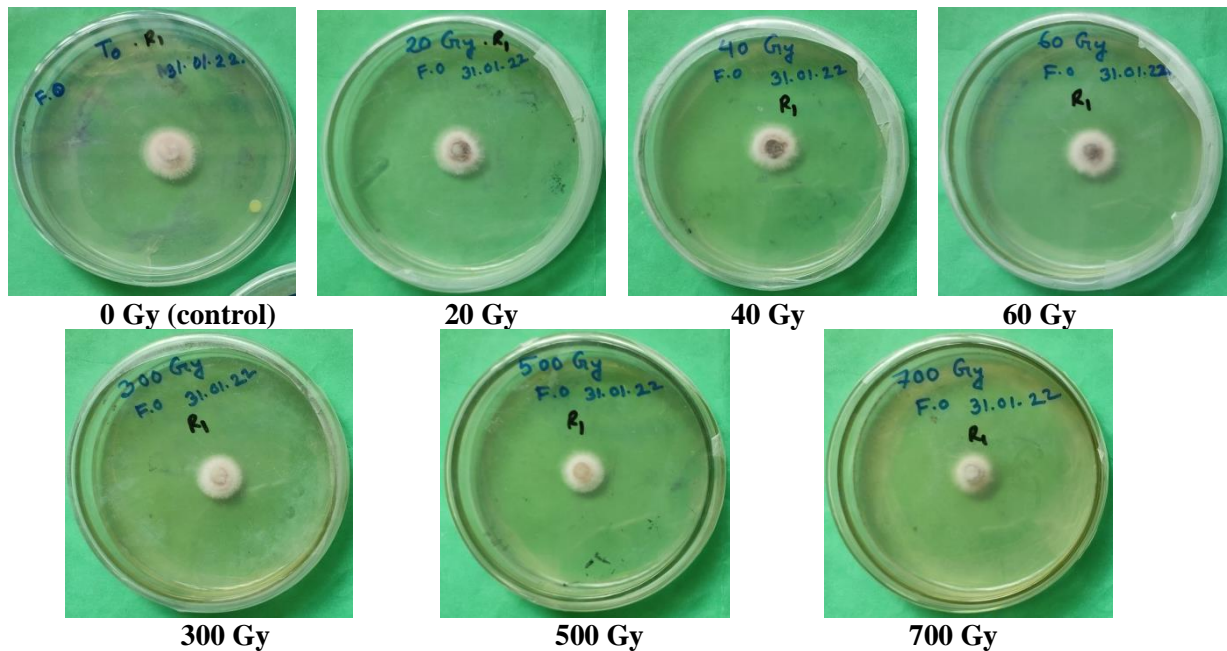


Figure 10: Mycelium growth (*Fusarium oxysporum*) at 1st day after irradiation.

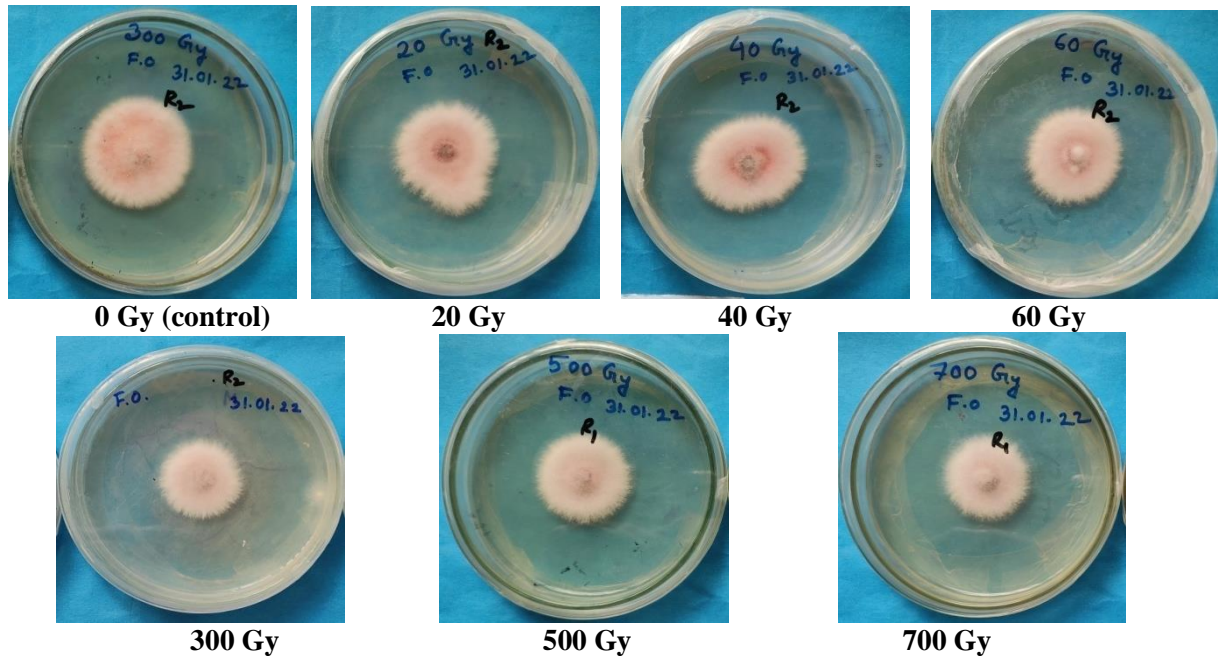


Figure 11: Mycelium growth (*Fusarium oxysporum*) at 3rd day after irradiation.

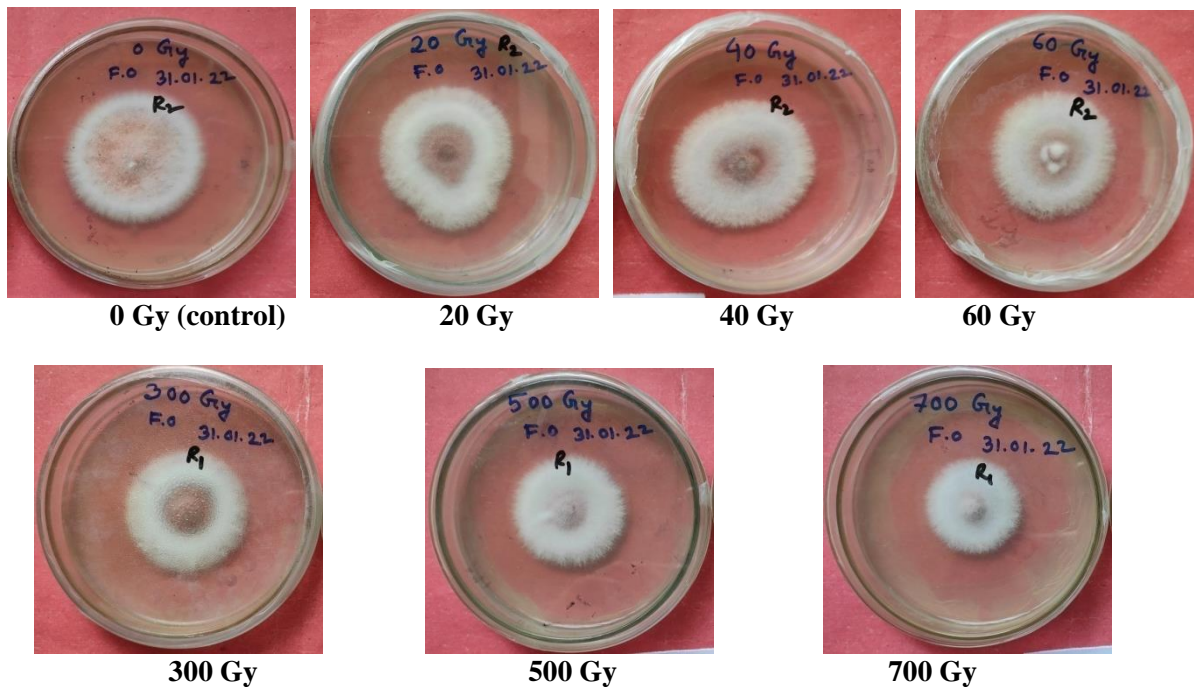


Figure 12: Mycelium growth (*Fusarium oxysporum*) at 5th day after irradiation.

Result of Dual culture assay of BINA Trichoderma against Fusarium oxysporum

By creating dual culture plates, *Trichoderma* sp. was tested for its antagonistic potential against *F. oxysporum*. It was shown that the antagonist grew more quickly than the pathogen after both fungi were inoculated in PDA plates. By day 5 of incubation, the antagonist had almost completely taken over all replicates of the plate, leaving

very little room for the pathogen to grow. On the seventh day of incubation, *Trichoderma* sp. had almost completely covered the entire plate. Comparing the means showed that *Trichoderma* sp. had much larger mycelial growth than *F. oxysporum*, with growths of 65.50 mm and 16.50 mm, respectively. Results showed that *Trichoderma* sp. significantly (78.15%) reduced the growth of *F. oxysporum*'s mycelia compared to control.

Table 5. Dual culture assay of BINA Trichoderma against Fusarium oxysporum.

Treatment	Mycelium growth (mm)							Mean	Growth inhibition over control (%)
	1st DAI	2nd DAI	3rd DAI	4th DAI	5th DAI	6th DAI	7th DAI		
Control	5.00a	11.00a	20.00a	32.00a	43.00a	57.00a	70.00a	34.00	
Trichoderma	3.00ab	9.50b	18.50b	30.50b	43.00b	55.00b	65.50b	32.14	
Fusarium oxysporum	0.00b	2.00c	3.50c	6.50c	10.50c	13.00c	16.50c	7.43	78.15
CV (%)	10.99	8.45	6.19	4.12	4.45	4.12	4.86		
LSD (0.05)	1.29	1.29	1.84	1.83	2.91	3.67	5.51		

In column, figures with similar letter do not differ significantly where figures with dissimilar letter differ significantly. DAI = Days After Inoculation,



Figure 13: Dual culture assay of BINA Trichoderma against Fusarium oxysporum. A. Control plate of Fusarium oxysporum. B. Dual cultured plate.

Result of poison food technique of Dithane M-45 against Fusarium oxysporum

At various points following inoculation, the impact of various Dithane M-45 (Mancozeb) concentrations on Fusarium oxysporum was noticed. After 5 days of incubation, the radial expansion of the colony was noticeably different at each of the three concentrations. The effect of DithaneM-45 on Fusarium oxysporum was seen in

the following ascending order: T3 (0), T2, T1, and T0 (2.41). After 5 days of incubation, T3's colony development was much lower (2%) than that of T1's (0.75%) and T2's (1%). According to the mean, T3 (2%) treatment had an up to 100% reduction in mycelium growth compared to T0 (control) treatment. T1 (0.75%) and T2 (1%), compared to control, showed decreases of 10.78% and 46.88%, respectively. (Fig.13)

Table 6: Effect of different concentrations of Dithane M-45 on Fusarium oxysporum.

Treatment concentration (%)	Mycelium growth (mm)			Mean
	1st DAI	3rd DAI	5th DAI	
T0.	2.00a	2.43a	2.80a	2.41
T1	1.7b	2.23a	2.53a	2.15
T2	1.00b	1.33b	1.53b	1.28
T3	0.00c	0.00c	0.00c	0
LSD (0.05)	0.21	0.36	0.41	
CV (%)	7.85	11.07	10.98	

In column, figures with similar letter do not differ significantly where figures with dissimilar letter differ significantly. Here, T0= Control, T1= 0.75%, T2= 1%, T3= 2%. DAI = Days After Inoculation

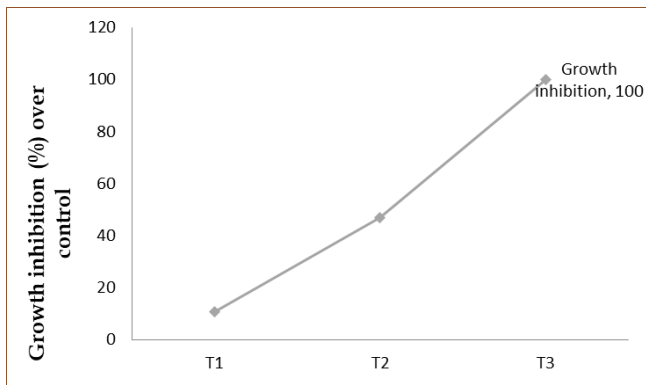


Figure 14: Mycelium growth inhibition (%) of Fusarium oxysporum against Dithane M-45 over control

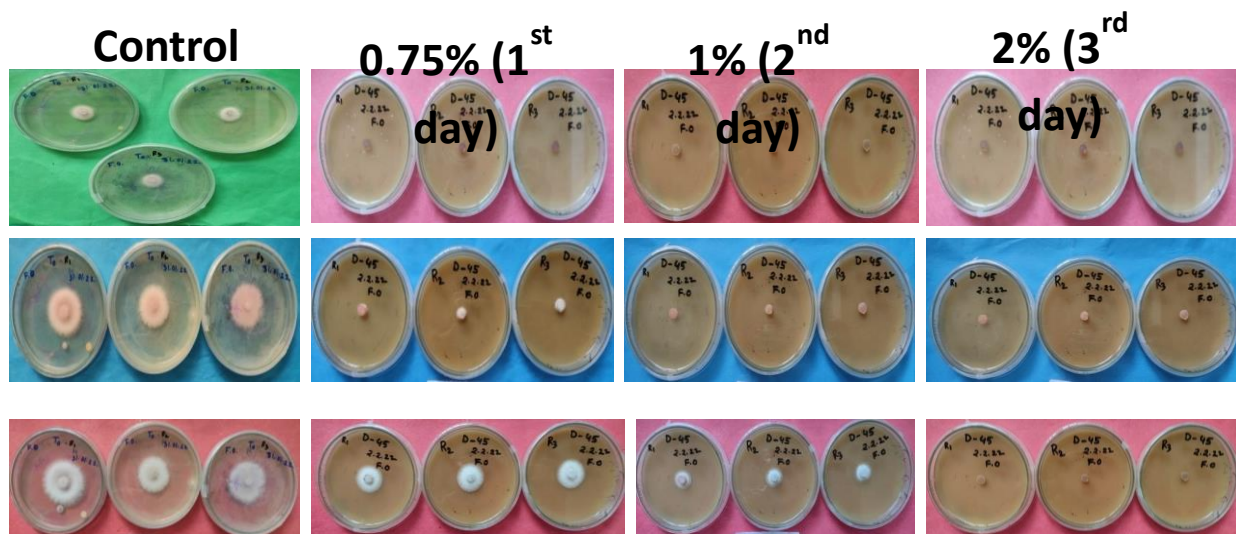


Figure 17: Mycelium growth of Fusarium oxysporum on different concentrations of Dithane M-45 at 5th day after inoculation

DISCUSSION

The experiment was carried out to evaluate the effect of Gamma irradiation against post harvest storage rot of Ginger caused by *Fusarium oxysporum*. *F. oxysporum* colonies were characterized by an abundant white cottony mycelium and a dark-purple undersurface on PDA. Its microconidia are oval to ellipsoid or kidney shaped. Macroconidia were oval tapering and septate with 3 cells (Leslie and Summerell, 2006 and Nelson et al., 1983). On Brown paper, the sprouting percentage in 60Gy, 300Gy, 500Gy & 700Gy was 0.00%. The sprouting percentage after three months of storage recorded higher for Trichoderma treated samples was 41.15% and in untreated or control samples was 26.46%. In Gunny bag, the sprouting percentage in 60Gy, 300Gy, 500Gy & 700Gy was 0.00%. The sprouting percentage after three months of storage recorded higher for Trichoderma treated samples was 36.33% and in untreated or control samples was 36.33%. In Poly bag, the sprouting percentage in 60Gy, 300Gy, 500Gy & 700Gy was 0.00%. The sprouting

percentage after three months of storage recorded higher for DithaneM-45 treated samples was 52.75% and in untreated or control samples was 47.48% (Yusof, 1990). Fresh ginger's shelf life is frequently shortened by sprouting, mold growth, shriveling, and softening (Yusof, 1990). The rhizomes are sold quickly after harvest because there is no adequate means of preservation, therefore they cannot be carried across long distances. Fresh rhizome storage is necessary to provide a year-round supply of fresh ginger (Pauli et al., 1988). According to Abdul et al., (1986), storage should take place at a relatively low temperature (10–15°C). The low-temperature storage method, however, is expensive in tropical climates or when being transported (Yusof, 1990). According to reports (Paull et al., 1988; Yusof, 1990), ginger can be stored in polythene bags with gamma-irradiation to prevent sprouting with DithaneM-45 (4g/l) or benomyl (500–2000 g/ml) to avoid mold growth. In this study, it was found that storing fresh rhizomes in closed polythene bags encouraged both sprouting and rooting as well as sped up the rates at which sprouts and roots grew. However, under these storage conditions, irradiation at a dose of 60 Gy followed by 300 Gy, 500 Gy,

and 700 Gy completely prevented both sprouting and rooting. The lowest disease incidence after three months of storage for Brown paper was recorded in 700Gy treated samples 56.83% and highest was recorded in control samples 88.41%. Among the chemical and bio-fungicide treated samples lowest incidence was recorded in Trichoderma treated samples 61.04%, whereas in DithaneM-45 treated samples was 66.72%. The lowest disease incidence after three months of storage for Gunny bag was recorded in 700Gy treated samples 68.15%, and highest was recorded in control samples 90.67 %. Among the chemical and bio-fungicide treated samples lowest incidence was recorded in Trichoderma treated samples 72.88%, whereas in DithaneM-45 treated samples was 79.00 %. In case of poly bag, after 90 days of storage all the samples in all the treatments showed almost 100% disease incidence. The lowest incidence recorded in DithaneM-45 treated samples was 82.65% and highest was recorded in control samples 100%. During post-harvest storage Ginger is susceptible to spoilage by sprouting, growth of fungi, and microbes. Washing and peeling make Ginger more prone to contamination from spoilage and pathogenic microflora (Mishra and Gautam, 2004; Jarrett, 1982) reported that the penetrating power of gamma-rays is more than fungicides thereby serving them to reach microorganisms inside the fruits of different sizes and shapes which are not accessible to chemicals. (Spalding et al., 1988) reported that Anthracnose rot incidence of mango was reduced by doses equal to or above 0.75 kGy dose. Lu et al. (1993) reported that Gamma rays in combination with biological control agent significantly reduced storage rot and delayed the ripening of peach fruits. (Lescano, 1994) observed that dosage of γ -irradiation (0.06-0.5 kGy) reduce in the level of microbial contamination (surface molds), and extend the shelf-life of mushrooms. (Prakash et al., 2002) observed significantly reduced microbial count of spoilage fungi of tomatoes at dose 0.5 kGy without any unacceptable changes in chemical, sensory and quality parameters of stored tomatoes. (Cia et al., 2007) reported that Gamma irradiation at 0.75 and 1 kGy inhibited conidial germination and mycelia growth in in-vitro of *Colletotrichum gloeosporioides* and reduced anthracnose incidence in 'Golden' papaya fruits. In this study significant reduction in disease incidence was observed in 700Gy treated samples (35.72%) on Brown paper compared to Gunny bag (24.83%) and Poly bag (12.11%) over control. The incidence of rot due to *Fusarium oxysporum* was found to be much higher in gunny and poly bag due to secondary spread of the pathogen from infected to healthy rhizomes inside the bag (Mishra et al., 2004). The lowest severity of storage rot disease of Ginger after three months of storage for Brown paper was recorded in 700Gy treated samples 73.31 % and highest severity was recorded in control samples 95.50%. Among the chemical and bio-fungicide treated samples lowest severity was recorded in Trichoderma treated samples 78.25%, whereas in DithaneM-45 treated samples was 80.67%. The lowest disease severity after three months of storage for Gunny bag was recorded in 700Gy treated samples 77.62%, and

highest severity was recorded in control samples 97.10%. Among the chemical and bio-fungicide treated samples lowest severity was recorded in Trichoderma treated samples 80.90%, whereas in DithaneM-45 treated samples was 85.89%. In case of poly bag, after 90 days of storage all the samples in all the treatments showed almost 100% disease incidence. The lowest severity recorded in DithaneM-45 treated samples was 88.50% and highest was recorded in control samples 100%. Compared with other perishable agricultural produce, fresh ginger is relatively less prone to spoilage because of its low moisture content and the presence of barriers such as scale leaves and antimicrobials. However, during post-harvest storage, ginger is susceptible to spoilage by growth of fungi and microbes (Mascolo et al. 1989). Gamma irradiation inactivates bacteria, molds, and yeast and controls some of the biochemical and physiological changes associated with ripening, maturation and sprouting (Urbain 1986; Diehl 1990; Diehl and Josephson 1994). On the other hand, chemical processing of food items leaves residues that could have hazardous effects on human health and the environment (Loaharanu 1994; Hallman 2001). Kader et al. (1986) suggested that the effectiveness of irradiation to control post-harvest diseases depends on the pathogen, its growth stage and the number of viable fungal cells on or within the tissue. (Spalding et al., 1988) reported that Anthracnose severity on 'Keitt' mango fruits was reduced by doses equal to or above 0.5 kGy. (Kilcast, 1995) reported that Gamma-irradiation is an ionizing radiation with high energy that removes one electron from water, creating highly reactive species including free radicals. The interaction of such species with the DNA of microorganisms brings about their death. (Cia et al. 2007) reported that Gamma irradiation at 0.75 and 1 kGy reduced anthracnose severity in 'Golden' papaya fruits. (Rico et al., 2010) reported that Gamma irradiation between 5.0 to 10.0 kGy generally meets expectation in eliminating microbial contamination. (Rezaee et al., 2011) concluded that severity was significantly reduced while shelf life of potato increased as a result of pre storage treatment with different doses of gamma irradiation in the range between 50 and 150 Gy. (Iqbal et al., 2013) observed that radiation at 6 kGy decreased the fungal contamination by 5 logs for red chilli. (Adriano Coasta de Camargo et al., 2014) reported that the contents of yeast and molds on peanut skin were reduced by at least three log cycles with a dose of 5.0 kGy. In this study significant reduction in disease severity was observed in 700Gy treated samples (23.24%) on brown paper compared to gunny bag (20.06%) and poly bag (8.41%) over control. The severity of rot due to *Fusarium oxysporum* was found to be much higher in gunny and poly bag due to secondary spread of the pathogen from infected to healthy rhizomes inside the bag (B. B. Mishra, S. Gautam et al., 2004). The treatment of gamma irradiation on growth of *Fusarium oxysporum* isolates showed that the radiation dose 700Gy completely inhibited the growth of *Fusarium oxysporum* after 3 days of irradiation. The same results were obtained in Roumania by Beljajevova (1960) and Paun et al., (1978) on testing sterilization of 30

types of molds who found a minimum effective dose of 7 kGy. Urban (1983) tested four types of molds- **Aspergillus flavus**, *Penicillium spinulosum*, *Chartonium globosum* and **Aspergillus niger** and found that the dose of 6 kGy eliminated all cultures tested. The complete inhibition of fungal growth was reported by (Smith and Pillai, 2004). After incubation for 7 days, results from a dual-culture of BINA *Trichoderma* against *F. oxysporum* showed that *Trichoderma* sp. significantly inhibited the growth of *F. oxysporum*'s mycelia compared to the control by 78.15%. As a more natural and environmentally friendly alternative to the current chemical treatments, biological controls have gained popularity recently (Dar and Soyong, 2014). It is one of the most effective techniques to keep agricultural productivity at its current level (Mishra et al., 2011). *Trichoderma* sp. is one of the several bacteria that are currently being employed as biological control agents for plant diseases. The fungus *trichoderma* is well known for having strong antagonistic effects against fungi infections. These characteristics were confirmed in several lab and field tests carried out in the Philippines and other nations against a wide range of soil-borne and airborne plant pathogens of various crops (Cuevas et al., 2005). This occurrence was also observed by (Sobowale et al., 2009) in his study on the interaction of *T. harzianum* strains and *F. verticillioides*. According to (Kumar et al., 2012), the rapid growth of *Trichoderma* isolates added an advantage to inhibit the growth of pathogens by competing for space and nutrients even before it deploys mycotoxins. According to the research of (Howell, 2003), *Trichoderma* is capable of growing tropically toward the hyphae of other fungus, coiling around them in a lectin-mediated response, and then destroying the target fungal's cell walls by secreting several lytic enzymes. By producing toxins or enzymes that cause the hyphae of the pathogen to shrink, dissolve, or even die, *Trichoderma* is able to combat fungal pathogens, according to Benitez et al. (2004). *Trichoderma* sp. was found to exhibit parasitic behavior toward *F. verticillioides* by adhering to the pathogen, coiling around, and strangling the hyphae, according to Nayaka et al. (2008). The effects of Dithane M-45 on *Fusarium oxysporum* were observed in the following ascending order: T3 (1), T2, T1, and T0 (2.80). According to (Sumitha and Gaekwad, 1998), Bavistin (Carbendazim), Topsin M-70 (Thiophanate methyl), and Thiram each at 0.18%, Captan at 0.15%, and Diathane Z-78 (Zineb) at 0.3% totally prevented the linear development of pathogens in culture (Bezbaruah et al., 1996). According to Pradhan et al. (1998), various amounts of zinc, iron, and boron significantly reduce the incidence of wilt. On PDA medium that had been amended with various test fungicide concentrations, *Fusarium oxysporum* colony growth was measured, and the results revealed a significant slowdown in growth. Thus, it was discovered that gamma irradiation was superior to chemical treatments for controlling post-harvest storage rot of ginger by reducing incidence and severity and was effective in extending the shelf life of stored ginger by inhibiting sprouting. Additionally, unlike chemical fungicides, gamma irradiation has no

lasting effects and poses neither a threat to human health nor a threat to the environment.

CONCLUSION

Utilizing gamma irradiation, brown paper packaging, and biofungicides such as *Trichoderma*-based products can be effective measures in managing post-harvest rot in ginger caused by *Fusarium oxysporum*, thereby improving the quality and shelf life of ginger during storage.

Based on the findings of the study, the following recommendations can be made:

1. Gamma irradiation at a dose of 700 Gy showed the highest suppression of mycelial growth and reduced disease incidence and severity. Therefore, the use of gamma irradiation at this dose can be recommended as an effective practice for controlling post-harvest rot in ginger caused by *Fusarium oxysporum*.
2. Brown paper was identified as the most effective container for storing irradiated ginger rhizomes, resulting in the lowest disease incidence and severity. Hence, it is recommended to use brown paper as a packaging material for irradiated ginger during storage.
3. The application of *Trichoderma*-based biofungicide and Dithane M-45 also exhibited significant reductions in fungal growth. Therefore, incorporating these biofungicides as part of an integrated management strategy can be considered to further enhance the control of post-harvest rot in ginger.

Conflict of Interest

There is no conflict of interest to declare.

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